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STRUCTURAL GEOLOGY AND GRAPTOLITES OF THE ORDOVICIAN ROCKS AT STEIGLITZ, VICTORIA, AUSTRALIA

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Abstract

Mesoscopic and macroscopic structures in the Ordovician sediments of the Steiglitz district have been mapped, described, and analysed. Three major macroscopic folds are recognized—the Moorabool Synclinorium, the Steiglitz Anticlinorium and the Anakie Synclinorium. In the north-eastern section, monoformal warping of the folded sediments occurs about steeply plunging axes. Two large faults, the Hanover and Rowsley, are described. Faunal analysis is given of graptolites occurring in the area, with description of one new species.

Introduction

The Steiglitz district is located about 20 miles NW. of Geelong. Ordovician sediments are exposed in the valleys of the Moorabool R., Sutherlands Ck and their tributaries where erosion has removed the Cainozoic sediments and volcanics which overlie the Ordovician rocks with strong angular unconformity. Although deeply weathered and often poorly exposed, the Ordovician sandstones and slates outcrop more or less continuously along the main streams.

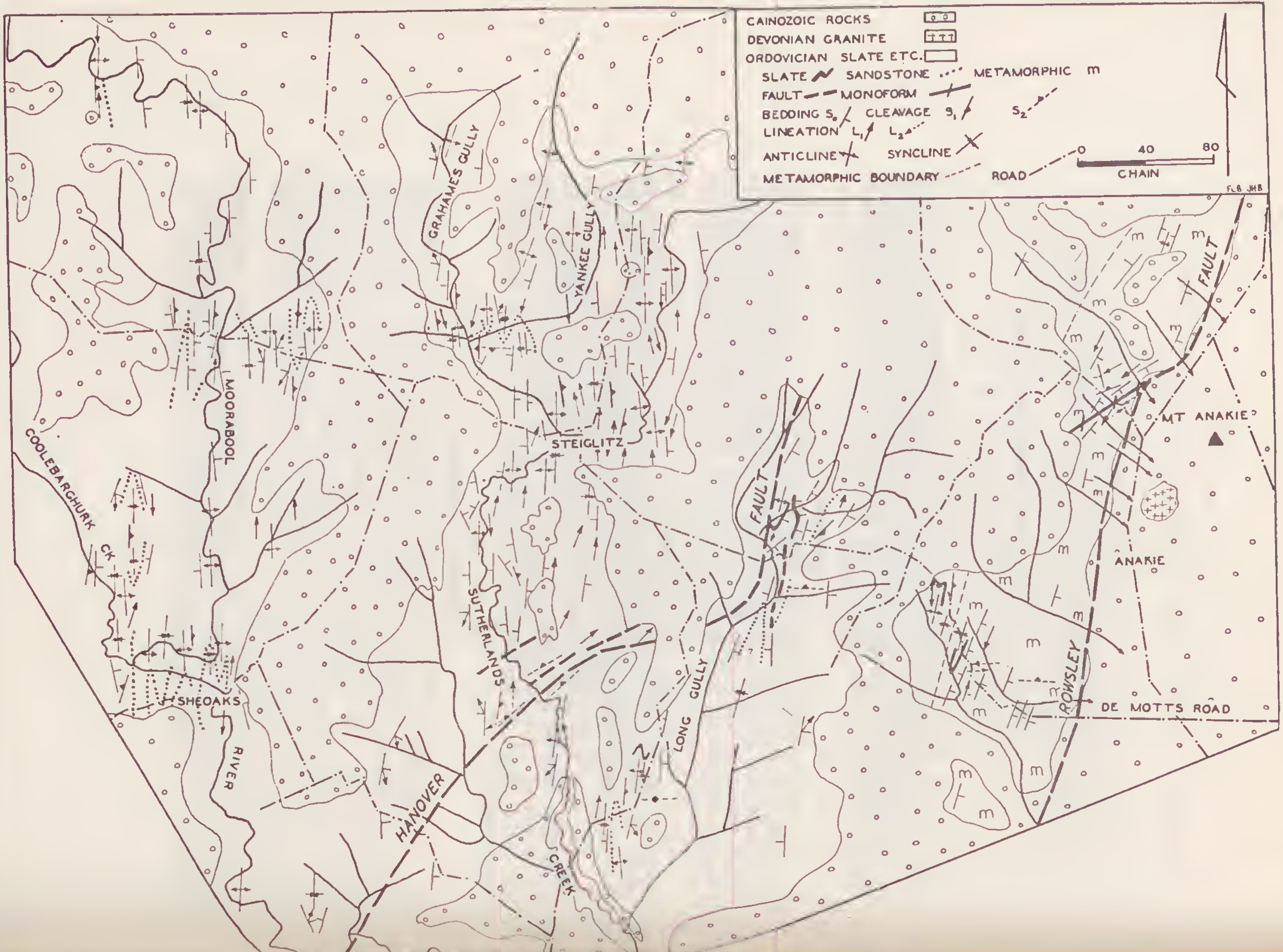
East of the Rowsley escarpment, granites are exposed as inliers in the Cainozoic basalts. The granitic rocks post-date the Ordovician sediments on which they have imposed a thermal metamorphism, the effects of which are apparent for a distance of about 1 mile W. from the escarpment.

In 1909, W. H. Ferguson mapped a narrow strip of terrain running north-south through Steiglitz township. This map was published in 1940. Some of the graptolites collected by Ferguson were identified by T. S. Hall who published lists of recognized forms (1913). W. J. Harris and D. E. Thomas (1949) described the broad aspects of the geology of the Meredith district, which included the Steiglitz area.

Mesoscopic Structures

The Ordovician sediments consist of shales, slates, siltstones and greywacke-type sandstones, with rare, thick orthoquartzites. Along the eastern margin of the area, the sediments, which had undergone very low-grade regional metamorphism during folding, have been thermally metamorphosed to spotted and andalusite slates, hornfels and metagreywackes. In the pre-Darriwilian beds sandstones are prominent in the lithology, but the Darriwilian beds are almost exclusively shale and slates, with only rare greywackes and quartzites. The lithology has exerted a marked influence on the style of the mesoscopic structures and on the geometry of the individual folds.

Throughout the sequence, simple and oscillatory graded bedding, convoluted bedding and current bedding are frequent, indicative of deposition of the sediments by turbidity currents. The beds have been tightly folded into asymmetric similar-style anticlines and synclines, with axial surfaces dipping steeply E., and


CAINOZOIC ROCKS
DEVONIAN GRANITE
ORDOVICIAN SLATE ETC.
SLATE
SANDSTONE
METAMORPHIC m
FAULT
MONOFORM
BEDDING S_0
CLEAVAGE S_1
S_2
LINEATION L_1 L_2
ANTICLINE
SYNCLINE
METAMORPHIC BOUNDARY
ROAD
0 40 80
CHAIN
FLB JHB
GRAHAMES GULLY
YANKEE GULLY
MOORABOOL
STEIGLITZ
COOLEBARGHURK CK
SHEOAKS
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MT ANAKIE?
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ROWSLEY
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axes plunging gently to the N. and S. Axial plane cleavages have been imposed on all the folded rocks, while slates and siltstones are strongly lineated.

(i) Folding

The closeness and tightness of the mesoscopic folds are variable; hinge lines may be spaced at intervals of from 5 ft to 600 ft. Normally, the fold hinges are sharp, but not angular. However, quite angular hinges occur in folded slate beds (Fig. 2) and in a folded sequence of sandstones they may be relatively open and rounded (Pl. 9, fig. 1). Rock type has controlled the form of the fold hinges. Fold axes plunge at angles usually less than 20° to the N. and to the S., and frequent change of plunge direction occurs throughout the area. The limbs of the mesoscopic folds dip steeply to the E. and W.; the westerly dipping limb is almost invariably steeper than the E. dipping limb, and consequently the folds are asymmetric with westerly vergence. Strike of limbs varies between N25°E and N25°W, and hinge lines trend a few degrees E. of N.

Several significant departures from these average attitudes were noted. One of these occurs in a narrow belt along the Hanover Fault and another in the NE. of the mapped area, near the flexure in the Rowsley Fault. In the Mariner's Gully area, adjacent to the Hanover Fault, mesoscopic fold hinges trend NE. to ENE., sub-parallel to the fault. This variation in trend, which is more pronounced N. of the fault than to the S., is regarded as a drag effect. In this belt also, fold hinges and lineations have plunges 10°-15° (and in isolated cases up to 50°) steeper than the regional average. Near the flexure in the Rowsley Fault, the mesoscopic structures have a complex geometry, and discussion of this area is deferred until later in this paper.

Throughout the area, even where relatively thick sandstones are involved, the style of the mesoscopic folds is 'similar'. Beds show thickening on hinges and thinning of limbs (Fig. 2), the effect being more pronounced in slates than in siltstones and sandstones. In many cases, the mesoscopic folds appear to be cylindrical, but there are a number of exposures in which the non-cylindrical geometry of the folds is obvious.

Fig. 2—Section in cliff near junction of Yankee Gully and Sutherland Ck. Length of section 25 ft.

(ii) Cleavages

Axial-plane slaty cleavage is perfectly developed in the slates; this cleavage has a more or less uniform easterly dip of 60° to 80°, but vertical-dipping slaty cleavage was noted locally on the Moorabool R., and west-dipping cleavage was recorded near the junction of Grahame's and Yankee Gullies. This east-dipping cleavage is a reflection of the westerly vergence of the folds. In the thicker slate beds, slaty cleavage is the dominant planar structure, completely obscuring bedding laminations. Although slaty cleavage is only weakly developed in, or absent from, the siltstones, these are broken, especially in the hinge zones of folds, by a cleavage with which is associated intense puckering of the bedding laminations. This cleavage, which has been referred to as strain-slip cleavage (Beavis 1965) is not a superposed structure. It was imposed at the same time as the slaty cleavage and represents the response of the siltstones to the folding stresses. The cleavage domains in the siltstones constitute the axial surfaces of the small folds or 'puckers' with which they are associated, and are statistically parallel to the axial surfaces of the larger mesoscopic folds in whose hinge zones the cleavage was formed.

The sandstones, too, are cleaved only in the hinge zones of mesoscopic folds. The only cleavage developed is 'fissuring' radially arranged about the axial surfaces of the folds, and statistically parallel to these surfaces: some particularly fine examples were noted at Sheoaks and at Grahame's Gully. Occasionally the fissuring forms conjugate sets, when it is finer than normal, and much more closely spaced.

There are several well defined zones, as well as some apparently isolated localities, where superposed crenulation cleavages, post-dating the main folding, have been recorded in slates, siltstones and hornfels. Superposed crenulation cleavage in this region was first observed at Ingliston in the contact aureole about the Ingliston granodiorite, where it was vertical, with E.-W. strike.

Near the Hanover Fault, in the Mariner's Gully area, the crenulation cleavage is parallel to the fault, with steep northerly dip (Pl. 10, fig. 1). In general, it is believed that the crenulation cleavage has been imposed by stresses associated with the intrusion of batholiths and with fault movement. The unique style of the cleavage (a true fracture cleavage) and its discordant geometry, indicate that it is unrelated to the main folding.

A fine crenulation cleavage was noted in Long Gully at two separate localities. In the more southerly, the cleavage forms the axial planes of small chevron folds in slates. At the more northerly occurrence, immediately S. of the Anakie-Steiglitz road, the cleavage forms the axial surfaces of small rounded flexures in steeply dipping slates. Both sets of folds have near vertical plunge, and are developed only over a very small area—less than 10 square ft. We would tend to interpret these occurrences, obviously unrelated to any major structure, as localized developments of discordant stress fields late in the folding of the sediments.

(iii) Linear Structures

The slates are strongly lineated, with lineations parallel to axes of the mesoscopic folds, or of segments of these folds. The two styles of lineation in the slates are microcrenulations in bedding planes due to the intersection of these by slaty cleavage, and colour layers in slaty cleavage planes, representing the trace of bedding laminae on the cleavage. The main linear structures in the siltstones are the hinge lines of the small puckers: these are restricted to the mesoscopic fold hinge zones. Elsewhere the siltstones show little or no linear structure.

Normally, the sandstones have no linear structures, but two styles occur in fold hinge zones: lozenges (Pl. 9, fig. 2) and mullions, due to the intersection of bedding by, respectively, conjugate and single sets of fissuring. On the Anakie-

Ballan Road, in the north-eastern sector, small fold mullions have been perfectly formed in a sandy siltstone, thermally metamorphosed to andalusite hornfels.

Superposed lineations, L2, are represented by fine cracks due to intersection of bedding and slaty cleavage by the crenulation cleavage S2. (Pl. 10, fig. 1). More typical L2 styles are fine crenulations in slates (Pl. 10, fig. 2-4).

Except where they occur on the hinges of mesoscopic folds, the superposed lineations have very steep plunge. In certain areas, for example on the Anakie Monoform, it was essential to distinguish between L2 and steeply plunging L1. The basis for distinction was the association of the lineation with S1 and S2, both of which were readily recognizable and distinguishable.

(iv) Geometric Analysis of Mesoscopic Structure

The geometric analysis of mesoscopic structural elements is shown on Fig. 3 & 4. Poles to the bedding, So, lie in a girdle with pole β, suggesting monoclinic symmetry and cylindrical folding. This is at variance with field observations, and, when other structural elements are considered (Fig. 3b, 3c) it is clear that the folding is non-cylindrical with triclinic symmetry.

The dominance of east-dipping cleavage, and of west-dipping bedding, is clearly shown on the diagrams, while the spread of B lineations (Fig. 3b) reflects not only some abnormally steep plunges, but also the overall non-cylindrical geometry of the folds.

The non-cylindrical triclinic geometry of the folded Ordovician rocks in this area is comparable to that of other areas of Ordovician rocks in Victoria where triclinic $B \perp B'$ geometry is characteristic. This geometry has been interpreted (Beavis 1967) as being the result of elongation in B during folding. Stresses

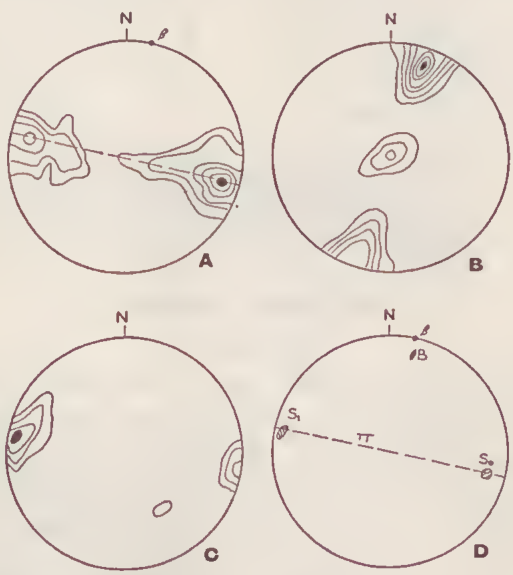

Fig. 3—Analysis of mesoscopic elements.
a. 167πSo. Steiglitz. Contours 1, 2, 5, 10, 15, 20%
b. 140 lineations L1, Steiglitz. Contours 1, 2, 3, 5, 10, 12, 15%
c. 92πS1, Steiglitz. Contours 1, 2, 10, 20%
d. Synoptic diagram.

developed normal to the compressive stresses causing the folding prevented this elongation and resulted in buckling about E.-W. axes. However, the present detailed study has shown that in the Steiglitz area, the geometry is a triclinic $B \wedge B'$ and cannot be explained by this hypothesis.

The geometry of surfaces and lineations in some selected localities of superposed structures is shown on Fig. 4. Because of the varying attitudes of the surfaces involved, there is a wide variation in the attitudes of the superposed lineation L2. Two sets of L2 occur except in some slates where L2 is represented by a single set of microcrenulations. In this latter case, the deformed L1 can be seen clearly (Pl. 2), but due to the smallness of the crenulations, measurement of the varying attitudes of L1 was not possible.

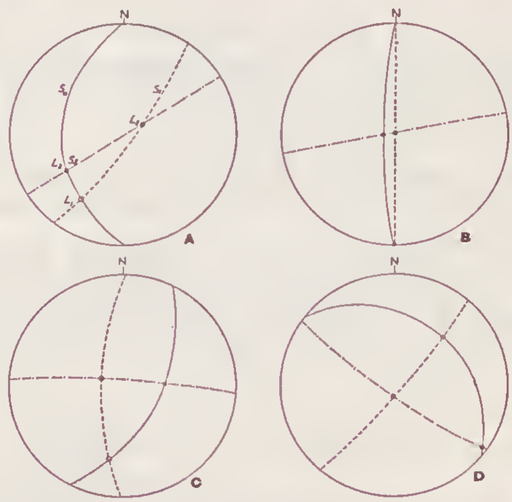

FIG. 4—Geometry of Superposed Structures.
a. Rowsley escarpment, Stony Ck, Anakie.
b. Junction of Yankee Gully and Sutherland's Ck.
c. Rowsley escarpment, de Motts Road, Anakie.
d. Sutherland's Ck, Mariner's Gully area.

Macroscopic Structure

(i) FOLDING

The form of the macroscopic folds, and the location of their hinge lines was determined from the distribution of graptolite zones and from mesoscopic data. In some cases, when prominent thick sandstone or slate beds could be traced in the field, lithological mapping could be used (Fig. 1). Graptolite zones were the main criterion, however, and since fossil localities are by no means uniformly distributed, the reliability of the mapping varied. Moreover, the Ordovician sediments are obscured in some critical areas by the cover of Cainozoic rocks. As a result of these factors, our interpretation of macrostructure, shown on Fig. 5, is only one of several possible. The reliability of our interpretation can be assessed from the frequency of graptolite localities, all of which are shown on Fig. 5. The forms collected from the most representative localities (numbered on Fig. 5) are listed in Table 1.

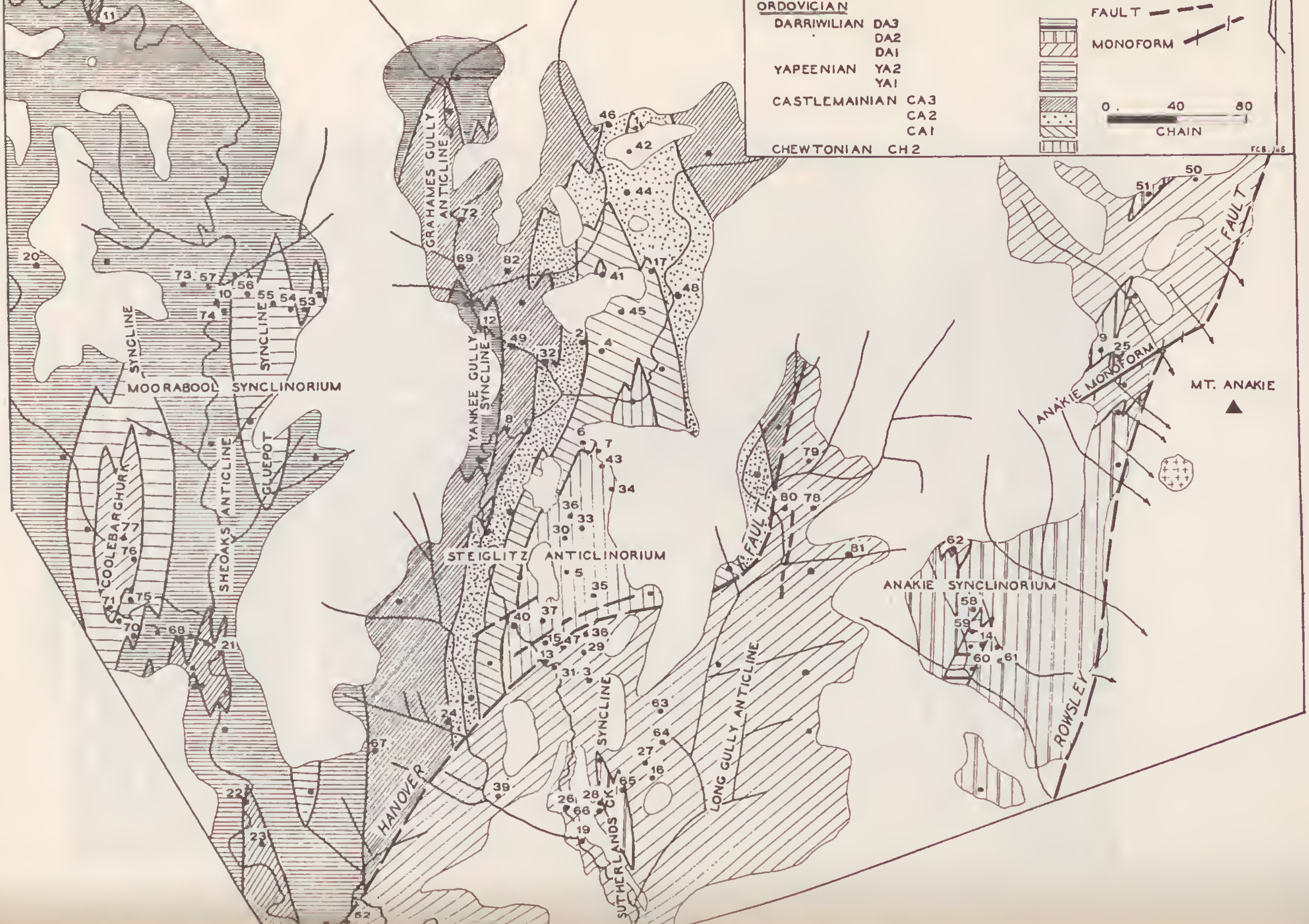

Fig. 5. Distribution of graptolite zones in the Steiglitz area, showing macroscopic folds

The sequence of Ordovician zones in the area studied ranges from Chewtonian (Ch2), the base of which is not exposed, through to Darriwilian (Da3). On the basis of detailed sections between Steiglitz and Meredith the thickness of the sequence in this area is of the order of 5000 ft. In spite of careful search, no evidence of the zone of *Didymograptus* cf. *balticus* (Ch3) was obtained, and it has been inferred that this zone is absent from the Steiglitz area, although it is known at Morrisons to the NW.

(a) **The Moorabool Synclinorium:** The lowest zone exposed in this fold complex is Castlemainian (Ca3) and the highest Darriwilian (Da1). The synclinorium consists of a number of small folds, which, because of plunge reversal, tend to be impersistent, with an irregular *en echelon* pattern.

Where plunge reversal is frequent, small folds (e.g. the Sheoaks Anticline) tend to break up into still smaller folds. The Synclinorium is a basin type structure with regional plunge reversal occurring on well defined SW.-NE. axes (Fig. 6).

The hinge line of the Synclinorium is not simple, and we regard the structure as consisting of two more or less equally developed synclinals separated by the Sheoaks Anticline. On the more westerly of the two synclinal hinge lines Da1 is exposed, and on the more easterly Ya2. The great breadth of outcrop of Ya1 beds in the Moorabool Synclinorium is due to repetition on very closely spaced mesoscopic folds.

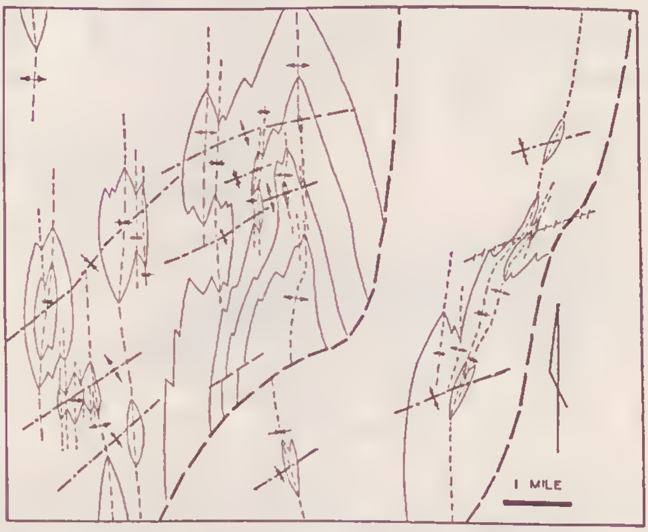

FIG. 6—Macroscopic structure of the Steiglitz area showing interpretation of macrostructure beneath Cainozoic cover, and B′ axes of plunge reversal.

(b) **The Steiglitz Anticlinorium:** The centrally situated Steiglitz Anticlinorium is the most prominent of the macrofolds, and is also the least complex of these. It is a relatively broad structure, with a gentle northerly plunge, terminated on the S. and E. by the Hanover Fault. The hinge line has a general NS. trend, but in the S. shows a slight swing to the SW. as the Hanover Fault is approached. To the N. of Steiglitz, near Durdidiwarrh, the hinge line becomes ill defined as the main anticlinorium tends to break up into smaller folds. Again, this behaviour is associated with well defined axes of plunge reversal. In the NW. sector of the western limb there is a loss of simplicity of the Anticlinorium, where, associated with reversal of plunge, the relatively large Grahame's Gully Anticline and the Yankee Gully Syncline have developed.

The greater outcrop width of the zones on the eastern limb of the Anticlinorium compared with that on the W., is a reflection of the greater steepness of the west dipping limbs noted for the mesoscopic folds. Because of the cover of Cainozoic sediments, little is known of the eastern limb of the Steiglitz Anticlinorium, and it is probable that our interpretation of this limb, shown on Fig. 6, is an over-simplification.

(c) **The Anakie Synclinorium:** Only Darriwilian beds are involved in this structure which is confined between the Rowsley and Hanover Faults, the latter separating it from the Steiglitz Anticlinorium. Because of the Cainozoic cover, little is known of this fold. There is a regional change of plunge in the de Motts Road area while a certain degree of complexity has been introduced by post-folding deformation on the Anakie Monoform. To the N., the main fold appears to be breaking up as a result of plunge reversal, and it is probable that the whole structure is more complex than we have been able to determine. The Sutherland's Creek Syncline W. from this fold may be a major structure, but we have not been able to obtain much data regarding it, nor of the anticline between this fold and the main Anakie Synclinorium. The hinge line of the Synclinorium differs slightly from that of the other macrofolds: it is remarkably sinuous, and has a general trend somewhat E. of N., rather than due N. like the Steiglitz Anticlinorium and the Moorabool Synclinorium.

(d) **The Anakie Monoform:** The term 'monoform' is used to describe this single-limbed fold structure, with steeply plunging axis, rather than the term monocline, which implies a flat, or very gently plunging axis. Anomalous attitudes of bedding, cleavages, fold axes and lineation, as well as overprinted cleavage, occur in a well defined belt associated with the flexure in the Rowsley Escarpment. Two hypotheses were considered: (i) that this belt represented drag effects, associated with an easterly extension of the Hanover Fault; or (ii) the flexure marked the dying out to the E. of the Hanover Fault. Both were rejected in the subsequent mapping of the Hanover Fault trending northerly in Long Gully. No evidence was found of rupture of the beds in this zone, and movement on the flexure was insignificant in comparison with displacement on the Hanover Fault. There may be some genetic relationship between the Anakie Monoform and the Hanover Fault, but because of the Cainozoic cover in this critical area, we have not been able to establish even a field relationship between the two structures.

Evidence of the Anakie Monoform, which has warped not only folded Ordovician sediments, but also the Rowsley Fault, is shown on Fig. 7. The area is in the zone of contact metamorphism, and the rocks involved are spotted slates, andalusite hornfels and spotted greywacke. Metamorphism is relatively high grade, but fossils preserved in dense black carbonaceous slates have not been destroyed. North of Stony Creek, beds have a N.-S. strike with steep dips E. and W., and fold axes (lineations) plunge 7°-12°N. Slaty cleavage dips E. at 70°. In the lower part of Stony Creek, bedding and cleavage show a marked swing to WSW.-ENE. with almost E.-W. lineations, and between the creek and the Anakie-Ballan Road, steepen to as much as 78° to the SW. and W. In cutting No. 2 there is a localized overturning with a reversed plunge 80° NE. on the hinge of a synform.

Between the Anakie-Ballan Road and the Cainozoic-capped ridge immediately S. from the road, bedding and cleavage have a more northerly (NE.-SW.) trend, and, in the gully S. of this ridge, strikes of bedding and slaty cleavage are once again N.-S. with plunges of lineations gently (10°) N.

An almost NE.-SW. vertical crenulation cleavage has been imposed on the rocks in the more highly deformed sections of the Monoform, such as cutting No. 2 and in the lower part of Stony Creek (Fig. 4a). On the basis of the mesoscopic data, it is inferred that the axis of the Anakie Monoform plunges steeply (60°-80°) to the W. The Monoform clearly post-dates the main folding and the initial movement on the Rowsley Fault. However, that the beds folded rather than faulted in response to the deforming stresses suggests high confining pressures and hence relatively deep burial during deformation.

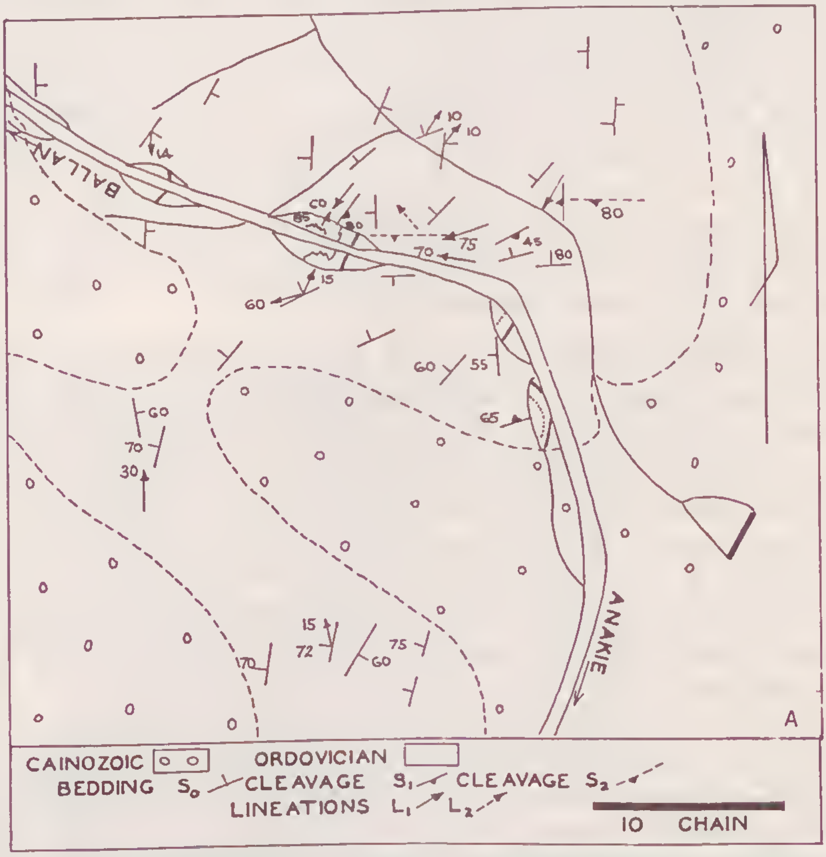

FIG. 7—The Anakie Monoform. Mesoscopic structural elements on the Monoform.

(ii) GEOMETRIC ANALYSIS OF MACROFOLDS

As noted previously, plunge reversal in the macroscopic folds occurs along reasonably well defined NE.-SW. axes (Fig. 6). These B′ axes, like the main B axes of the folds, tend to be discontinuous with a tendency to an *en echelon* pattern. The effect of plunge reversal on B′ axes has been to impart a triclinic $B \wedge B'$ symmetry to the folded mass: a fact not suggested by the π diagrams. This triclinic $B \wedge B'$ geometry does not imply separate unrelated deformation on B and B′, but rather buckling about B′ synchronously with folding about B. The non-coincidence of B and β which emerged from the geometrical analysis of bedding and lineation (Fig. 3) is of interest.

The plunge of the individual mesoscopic folds is some 10°-15° steeper than that of the regional system. Such a feature is characteristic of *en echelon* folding (Campbell 1959) and implies the activity of shear couples in the folding: a view supported by the triclinic $B \wedge B'$ geometry.

(iii) Faulting

In the area mapped two major faults occur, both of which had been recognized by earlier workers. During the present work, these faults were studied in some detail, and we were able to show the Hanover Fault extending westerly to Long Gully, and thence northerly. Several minor faults were also recorded.

(a) **The Hanover Fault:** Ferguson (1940) recognized and mapped the Hanover Fault as the 'Hanover line of lode' in the Mariner's Gully area. The south-westerly extension of this structure to the Moorabool R. was subsequently established by Harris and Thomas (1949) who described it as a high angle thrust. Across the Hanover Fault there is a strong contrast in lithology: to the S. and E. slates predominate, while to the N. and W., sandstones and siltstones are the dominant rock types. This is a reflection of the stratigraphic break across the fault: to the S. and E. all of the rocks are Darriwilian, while to the N. and W. they range from Chewtonian through to low Darriwilian. The Hanover Fault lacks any physiographic expression, and it is on stratigraphic evidence alone that movement on the fault can be assessed.

Two areas in particular were suitable for detailed study of the Hanover Fault: the Mariner's Gully area (Fig. 8) and Long Gully. In the former area, there is marked drag of bedding and slaty cleavage, and of fold axes with abnormally high plunges. The fault itself is marked here by brecciation of sandstone and crushing of slates to a dense black gouge, while mineralization of the fault is reflected in scattered quartz at the surface.

The stratigraphic break across the fault in this area is considerable. Fossils in the northern block are Chewtonian (Ch2) while with one exception, the localities on the south of the fault yielded Darriwilian (Da1) fossils. The exception was locality 47 which yielded *Didymograptus protobifidus*. This locality is a mine dump almost on the fault, and we infer, with Harris and Thomas, that the fossiliferous material was mined on the N. side of the fault.

Associated with the fault and more or less parallel to it is a fracture cleavage which has deformed the bedding slightly and imposed a second lineation (Pl. 10, fig. 2).

Ferguson recorded the dip of the Hanover Lode as northerly. This was confirmed by observation in an old mine shaft where brecciated and mineralized rocks dipped 70°N., and cut across the bedding. Associated with the Hanover Fault and parallel to it are two minor faults. These are regarded as parallel shear zones which developed synchronously with the Hanover Fault.

Harris and Thomas, from their studies in this area, regarded the Hanover Fault as a high angle thrust and estimated the thickness of missing beds across

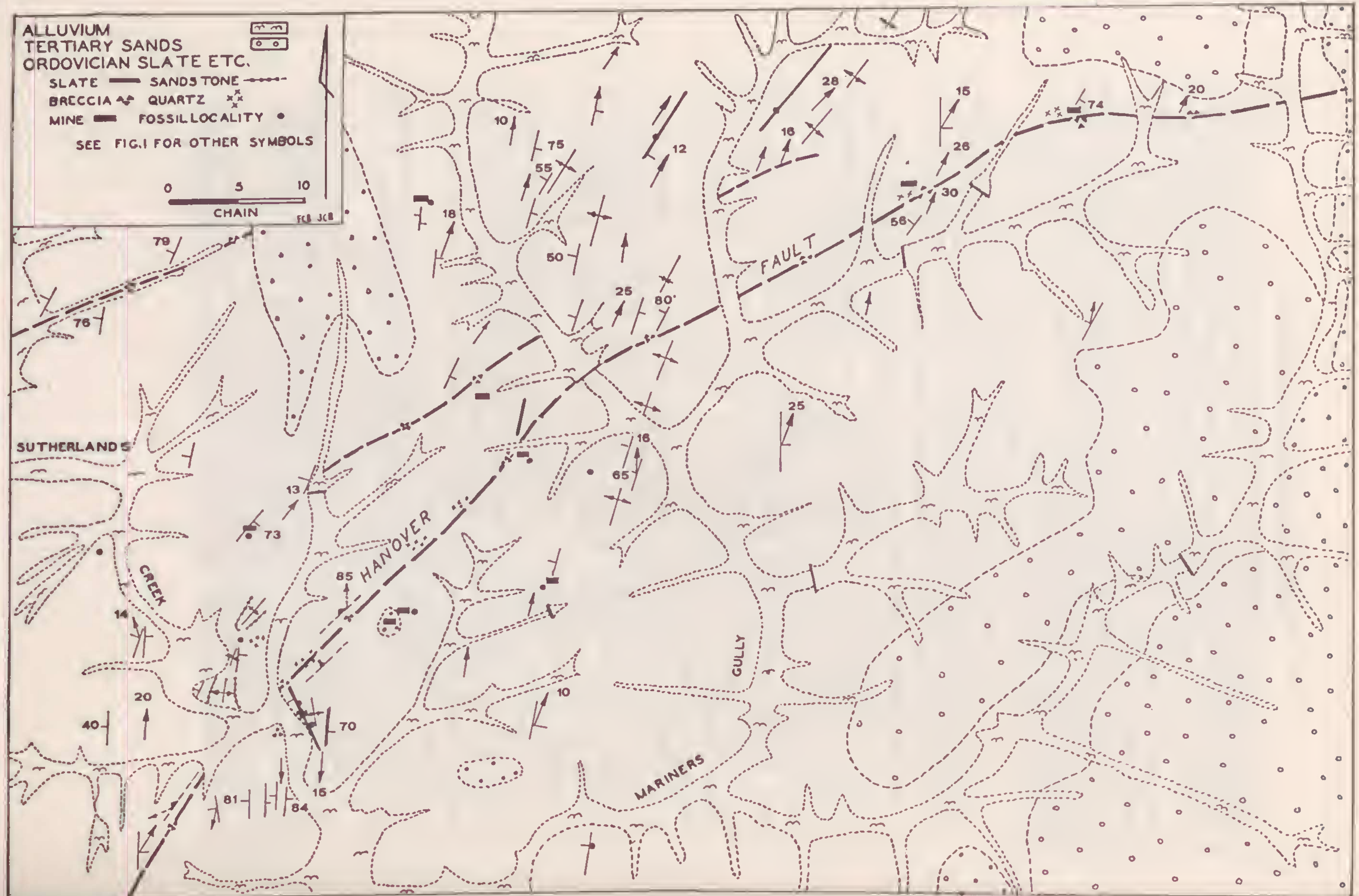

Fig. 8—Geological map of the Hanover Fault in the Mariner's Gully area.

the fault as of the order of 2000 ft. We agree that the evidence of macroscopie structure supports the concept of thrusting, but believe that there was a considerable component of strike slip indicated by such phenomena as drag of planar and linear structures.

In Long Gully, there is evidence of faulting similar to that observed at Mariner's Gully. Brecciation over a relatively narrow zone (5-10 ft) was noted. Here, the fault has an almost due northerly trend, with high Castlemainian beds abutting against low Darriwilian. Associated with the fault here, also, is a minor fault to the E., marked by brecciation. Some mineralization is evident in this area, but it is associated with the minor fault, and not with the main structure. Here, there is little evidence of drag: this may be due to the fact that, in Long Gully, the bedding and fault are almost parallel. There is, however, some sign of drag in abnormally steeply plunging fold axes.

In Long Gully, the Hanover Fault curves round from its NE. trend to northerly and, as well as a fine superposed cleavage parallel to the fault, there is locally a fine cleavage which, from the few observations, appears to be disposed radially to this curvature.

North of the Anakie-Steiglitz road, the Ordovician rocks are overlain by Cainozoic sediments, and the Hanover Fault is not exposed. Further N., on Stony Creek between Durdidiwarrh and Staughton Vale, outside the area studied here, Castlemainian and Yapeenian beds abut against Darriwilian, the boundary being a N.-S. fault. This is almost certainly a northerly extension of the Hanover Fault.

(b) **The Rowsley Fault:** A well preserved, slightly dissected, E.-facing escarpment marks the line of the Rowsley Fault. Fenner (1918) regarded this structure as a normal fault, downthrown to the east, on which displacement occurred comparatively late in the history of the area. Other workers are at present studying the relationship of the fault to Cainozoic rocks: we have confined our attention to the Ordovician sediments. The fault escarpment has an almost N.-S. trend, with a slight but significant flexure N. of Anakie township and immediately W. of Mt. Anakie. Difference in level across the escarpment is of the order of 350 to 450 ft.

Study of the Ordovician rocks along this escarpment has led us to conclude that it is due to late normal faulting along an older fault line, on which the earlier movement was possible thrusting due to compressive stresses. The flexure referred to above is the result of deformation of the old fault by the Anakie Monoform. Evidence which leads to this conclusion includes mesoscopie structures which could be induced only by shear stresses, and not by tensile stresses required for normal faulting. The evidence includes, particularly, crenulation cleavage in the Ordovician sediments, parallel to the escarpment, and crumpling of bedding both on a small and large scale. In spite of the sharpness of the escarpment, and some excellent exposures in ravines, we did not observe the actual fault zone. Immediately E. from the fault, the only exposed rocks are Newer Volcanics and Devonian granites: it is thus impossible to determine in this area the stratigraphic displacement on the original fault. The width of the contact metamorphic rocks W. from the escarpment is sufficiently great to suggest that the displacement was of no very high order of magnitude.

(c) **Minor Faults:** Three minor faults, all associated with the Hanover Fault, were noted above. Several other small faults were recorded, all with small displacement, and all roughly parallel to the strike of the Ordovician rocks which they disrupted. One of these occurs near the Anakie Monoform, and two N. of

Steiglitz township. Other minor faults almostly certainly occur but poor exposure, and the nature of this study, precluded the possibility of the detailed field work required to record them.

(d) **Age of faulting:** No direct evidence of the age of either the Hanover Fault or the initial movement on the Rowsley Fault exists. The latest movement on the Rowsley Fault was more or less contemporaneous with the Newer Volcanic activity of Mt. Anakie and related centres. The Hanover Fault, overlain by Cainozoic sediments is certainly pre-Tertiary in age. The nature of the crush zone suggests that at the time of disruption, the rocks were in a brittle condition: a conclusion supported also by the nature of the superposed cleavage associated with the fault. Assuming that mineralization of the fault was associated with granitic intrusion, it could then be concluded that the fault pre-dated intrusive activity. However, there is virtually no evidence to support the basic assumption. There is no direct evidence of the age of the initial movement on the Rowsley Fault. The geometric relationship and the similar forms of deformation of this fault and the Hanover Fault suggest contemporaneity, but there is no conclusive evidence. The Rowsley Fault certainly predated the Anakie Monoform, and, since reasonable confining pressure would have been required for this flexure to develop as such, and not as a fracture structure, it is concluded that erosional uncovering was slight at the time, and the depth of burial reasonably great.

(iv) Structure and Ore Deposition

Active gold mining in the Steiglitz gold field ceased in the early years of this century. Gold was won economically from two main areas: the 'Central Area' about the township of Steiglitz, and the Mariner's Gully area. The only workings we noted outside these two areas were on Coolegurbark Ck and on a spur rising W. from Long Gully. Both these were shallow, and apparently unproductive. The only economic ore bodies were located on the Anakie Anticlinorium. In the Mariner's Gully Area, ore bodies were localized on the Hanover Fault, but even here, fault mineralization has occurred only along that part of the fault which cuts the hinge zone of the Anticlinorium. In the central area ore bodies occur in zones ranging from Ch2 to Ca3 so that a stratigraphic control of ore deposition cannot be accepted. The ore deposition was centred on the hinge zone of the Steiglitz Anticlinorium, and the gold field is limited by this structure.

The Hanover Fault forms the southern and eastern boundaries of the gold field. Because of the cover of Cainozoic rocks, the northern boundary is not known. However, the breaking up of the Steiglitz Anticlinorium to the N. of the area mapped suggests that here the economic ore also terminated.

Discussion of Structure

Three major macroscopic folds occur in the Steiglitz area: the Moorabool Synclinorium; the Steiglitz Anticlinorium, on which deposition of gold was localized; and the Anakie Synclinorium, separated from the other two macrofolds by the Hanover Fault which forms the southern and eastern boundaries of the Steiglitz gold field. The Anakie Monoform has locally deformed the folded Ordovician sediments and the Rowsley Fault.

One of the more interesting features of the structure in the Steiglitz area is the pattern and geometry of folding. The folds have an *en echelon* pattern, with fold hinges trending almost N.-S. Reversal of plunge occurs on discontinuous NE.-SW. axes, which also have an *en echelon* pattern. The total geometry is a triclinic $B \wedge B'$ type. With the exception of the Anakie Monoform, which has uniquely

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
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Ch2	Da1	Da1	Ch2	Ch2	Ca2	Ch2	Ca2	Ca1	Ca3	Ch2	Ca2	Ca3	Da1	Da2	Da1	Ca3-Ya1	Ya2	Ya2	Ya2	Ya1	Da2	Da3	Da	Da2	Da1	Da1	Da1	Da1-Da2	Da1	Ca3	Ca3-Ya1	Ca3	Ya1-Ya2	Da1	Ca3	Ya1	Ya1	Ya2	Da1	Da1	Da1	Da1	Da1	Da1	Ca3

During the close examination of some hundreds of specimens, only one new species was recognized: *Isograptus pertensa* (Harris). Several *Didymograpti* and one *Pterograptus* may be new species, but the specimens were too poorly preserved for detailed study. These specimens, however, have been lodged in the collection of the Geology Department, University of Melbourne (Nos. 3676, 3677, 3678) for possible future study. Formal description of *I. pertensa* is given here. Otherwise only incidental reference is made to morphological characters. Table 1 lists the representative collections made during the survey.

Chewtonian Fauna

The lowest zone recorded in the Ordovician rocks was that of *Didymograptus protobifidus* (Ch2). Beds of this zone are exposed along the hinge zone of the Steiglitz Anticlinorium. Ch3 beds were not recorded between Ch2 and Ca1, and it is possible they were not deposited, or are so thin that, in spite of careful search, they were passed over during the survey. At Morrisons, to the north west of the area studied, Harris and Thomas (1949) recorded relatively strong development of this zone. The following species were collected from Ch2 beds at Steiglitz.

Didymograptus cf. *D. extensus* J. Hall
Isograptus caduceus var. *primula* Harris
Phyllograptus cf. *P. typus* J. Hall
Phyllograptus sp.
Dichograptus separatus Elles
Didymograptus cf. *D. extensus* J. Hall
Dichograptus octobrachiatus J. Hall
Tetragraptus bryonoides J. Hall
Tetragraptus serra Brongniart
Tetragraptus quadribrachiatus J. Hall

Morphologically, the zonal fossil *Didymograptus protobifidus* exhibits a wide variability. The most prominent of these variations is the range in angle of stipe divergence, which is proximally 80°-110°, and distally, 10°-45°, figures which compare closely with those recorded by Ripper (1937). At Steiglitz, the increase in angle of divergence is accompanied by an increase in width of stipes, but all variants occur together, and because of the restricted thickness of the Ch2 beds, no conclusion can be reached concerning the evolutionary significance, if any, of these features.

I. caduceus var. *primula* is a small form which seems to be restricted to the upper beds of the zone, and marks transition to Ca1. *Phyllograptus* cf, *typus* is also a relatively common species. Extensiform *Didymograpti* are rare: a few specimens of *D.* cf. *extensus* were collected (loc. 41).

Castlemainian Fauna

In spite of the wide distribution of Castlemainian beds, fossil localities are by no means common, and we are forced to conclude that great thicknesses of the Castlemanian beds in this area are unfossiliferous. The fauna is characterized by variants of *Isograptus caduceus*, and these are always the most abundantly occurring forms at any locality. The Ca1 fauna includes:

Isograptus caduceus var. *primula* Harris
Isograptus caduceus var. *lunata* Harris
Phyllograptus angustifolius J. Hall

for the area, affected the B folds, and is clearly associated with superposed structures, the triclinic $B \wedge B'$ symmetry generally in the Steiglitz area does not imply separate, unrelated folding deformations. So far as we can ascertain (Whitten 1966 and references) most examples of this fold geometry through the world would have been ascribed to two (or more) foldings. Here, however, there is evidence of one deformation only.

The folding mechanism involved both flow and flexural slip with localized flow in the siltstones and sandstones, with considerable transposition along cleavages in fold hinge zones in siltstones, and throughout the folds in slates. With such folding mechanism, elongation parallel to the fold axes, B, was an important element of the movement picture. Prevention of movement parallel to B or restriction of this movement, together with the development of shear couples within the deforming mass in part as a result of this resistance, would produce a fold pattern with the geometry pattern and symmetry occurring at Steiglitz.

The field relationships of the Hanover and Rowsley Faults to the Anakie Monoform suggest a genetic relationship. Shear stresses to produce this monoform could be developed in the rock mass from the normal compressive stresses responsible for thrust movements on the faults.

The stresses responsible for the fault movements were also responsible for the superposition of some of the crenulation cleavage on the already folded rocks, and for some of the superposed linear structures in the previously folded slates. Other cases of superposed cleavage appear to be the result of stresses associated with igneous intrusive activity, and a few rare cases may be associated with localized stresses in developing parasitic 'drag' folds during the main folding.

Graptolites of the Steiglitz Area

Apart from incidental reference in various publications by Harris, Harris and Thomas, and Harris and Keble, the only record of the graptolites in the Steiglitz area is that of T. S. Hall (1913) which is simply a list of forms from a few of Ferguson's (1940) localities. During the present survey, over 50 species were collected from almost 100 localities, as well as a number of specimens too poorly preserved for specific identification, notably *Tetragrapti* and *Phyllograpti*. Even when well preserved, the *Phyllograpti* could often not be referred definitely to a particular species, and could be listed only as a comparison (Table 1).

The graptolites in the Steiglitz area are found in dense black or red-grey slates, although the fossiliferous Darriwilian Beds are grey, fawn and purple shales and slates and black pelitic hornfels. In the eastern sector of the area, where the sediments have been thermally metamorphosed, the graptolites are preserved in the hornfels as aggregates of fine golden mica flakes; all morphological detail has been destroyed by the metamorphism. Fossil localities were found more commonly in the Darriwilian and were least common in the Castlemainian.

Collection of specimens from obviously richly fossiliferous beds was often difficult due to the acuteness of the cleavage-bedding intersection (particularly in the central sector of the area) and the deep weathering of the rocks.

The fauna is dominated by Isograptids which appear in the oldest beds of the area (Chewtonian, Ch2) and which persist through to the lower parts of the Darriwilian (Da1).

In quantitative terms, the Isograptids reached the peak of their development in the Yapeenian and in the Darriwilian gave way to the Diplograptids which dominate the fauna from Da1 through to the highest beds in the area, Da3.

TABLE 1—*Graptolite Fauna, Steiglitz*

Locality (Fig. 5)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Species:																																		
Dichograptus sp.		X																																
separatus																														X				
octobrachiatus																																X		
Didymograptus sp.		X													X		X				X		X	X										
?n. sp.										X																								
?n. sp.				X																														
extensus	X			X			X																											
distinctus											X	X						X														X		
serratulus												X																						
protobifidus					X										X															X			X	X
nitidus	X																																	
gracilis																														X				
v-deflexus																																		
compressus																																		
Tetragraptus sp.					X																					X		X	X					
bryonoides	X						X					X															X		X		X	X	X	X
serra			X	X			X																										X	X
quadribachiatus																																	X	
similis																														X		X		
Phyllograptus sp.												X		X																X		X		
angustifolius						X	X																											X
cf. anna							X																											
cf. typus	X			X	X																													
cf. densus											X							X																
Isograptus caduceus																																		
var. primula					X		X																							X			X	X
lunata	X			X													X																	
victoriae		X				X					X							X				X		X								X		
maximus								X		X	X							X			X	X	X	X										
divergens			X							X			X							X						X			X					
maximo-divergens													X													X		X			X			
Isograptus pertensa													X																		X			
hastatus																											X							
forcipiformis																																		
manubriatus																																		
Oncograptus upsilon												X																						
Cardiograptus morsus																																		
crawfordi																									X	X								
Cryptograptus tricornis.													X																		X			
Lasiograptus etheridgei											X							X																
Loganograptus logani																			X						X	X	X	X	X					
Glossograptus hincksii			X																															
acanthus													X												X	X	X							
Trigonograptus wilkinsoni										X																								
Pterograptus ?n. sp. (MU. 3676)			X													X			X							X	X		X		X			
Glyptograptus sustrodentatus																									X			X						
intersitus									X																X		X	X						
Diplograptus sp.														X																				
decoratus.																																		
Zone	Ca1	Ca2	Da1	Ca1	Ch2	Ca2	Ca1	Ca3	Da	Ca3-Ya1	Ya1	Ya2	Da1	Da3	Ch2	Da1	Ca1	Ca3-Ya1	Da1	Ya1	Ca3	Ca3	Ca3	Ca3	Da2	Da1	Da1	Da2	Da1	Ch2	Da1	Ca2	Ch2	Ch2

Phyllograptus cf. *P. typus* J. Hall
Didymograptus extensus J. Hall
Didymograptus nitidus J. Hall
Tetragraptus bryonoides J. Hall
Tetragraptus serra Brongniart

I. caduceus var. *primula* was collected from one locality only (45), about midway through the Ca1 sequence; var. *lunata* is the dominant isograptid of this fauna.

Ca2 forms include:

Isograptus caduceus var. *victoriae* Harris
Phyllograptus angustifolius J. Hall
Phyllograptus sp. (small form)
Dichograptus octobrachiatus J. Hall
Didymograptus extensus J. Hall
Tetragraptus?bryonoides J. Hall
Tetragraptus serra Brongniart
Tetragraptus similis J. Hall

D. octobrachiatus is rare, and was collected only at loc. 32; *I. caduceus* var. *victoriae* was abundant at all localities.

The uppermost Castlemainian beds are particularly unfossiliferous, and the fauna is a narrow one. The zone fossil *Isograptus caduceus* var. *maximus* is always abundant, but was sometimes the only species collected. Occasionally var. *victoriae* was found: this was not restricted to the lower part of the zone, but was also found in beds transitional to the Yapeenian. Some localities referred to transitional Ca3-Ya1 included *I. caduceus* var. *divergens* with abundant var. *maximus*. The Ca3 fauna is:

Isograptus caduceus var. *maximus* Harris
Isograptus caduceus var. *victoriae* Harris
Isograptus caduceus var. *divergens* Harris
Phyllograptus angustifolius J. Hall
Didymograptus spp.

Yapeenian Fauna

The zonal fossils *Oncograptus upsilon* and *Cardiograptus morsus* are not found typically in the Yapeenian assemblages. The Ya1 fauna includes:

Oncograptus upsilon Harris and Keble
Isograptus caduceus var. *maximus* Harris
Isograptus caduceus var. *divergens* Harris
Isograptus caduceus var. *victoriae* Harris
Isograptus pertensa (Harris)
Loganograptus logani J. Hall
Phyllograptus spp.
Didymograptus extensus J. Hall
Didymograptus spp.

Oncograptus upsilon was collected only at localities 57, 73 and 74. *I. caduceus* var. *divergens* is the most abundant fossil. *I. caduceus* vars. *maximus* and *victoriae* are found only sporadically, and then low in the zone. *Loganograptus logani* appears at the base of Ya1 and is a typical Yapeenian form. One of the most interesting aspects of the fauna is the occurrence of *Isograptus pertensa*

(Harris). This species, described as a variety of *I. caduceus* by Harris (1933) had been recorded only from Darriwilian beds on Sutherland's Creek. Its occurrence at loc. 68 on the Moorabool R., Sheoaks, in beds transitional from Ca3 to Ya1 extends its range downwards considerably, and demands a review of its genetic relationships.

The Ya2 fauna is an exceptionally rich one, but, like the Ya1 fauna, it is dominated by variants of *I. caduceus* and closely related species:

Cardiograptus morsus Harris and Keble
Isograptus caduceus var. *divergens* Harris
Isograptus caduceus var. *maximus* Harris
Isograptus caduceus var. *maximo-divergens* Harris
Isograptus forcipiformis Ruedemann
Isograptus hastatus Harris
Isograptus manubriatus T. S. Hall
Didymograptus v-deflexus Harris
Didymograptus distinctus Harris and Thomas
Didymograptus ?n. sp.
Didymograptus sp.
Pterograptus ?n. sp.

Isograptus hastatus (locs. 54, 55, 56) and *I. manubriatus* (loc. 56) are comparatively rare. *I. hastatus* was recorded from Steiglitz by Harris (1933) but *I. manubriatus* has not been recorded previously from this area. *I. hastatus* appears several hundred feet lower in the sequence than *I. manubriatus*. The two species are found together in a synclinal hinge near the top of the Yapeenian, while *I. manubriatus* was recorded even higher in the sequence from Da1 (loc. 76).

Darriwilian Fauna

At the top of Da1, the Isograptid fauna is extinct, and except for an occasional locality at the base of the zone, the fauna throughout the Darriwilian is Diplograptid. The Da1 fauna includes:

Glytograptus austradentatus Harris and Keble
Trigonograptus wilkinsoni T. S. Hall
Lasiograptus etheridgei Harris
Glossograptus hincksii Hopkinson
Cryptograptus tricornis Carruthers
Phyllograptus sp. (small form)
Isograptus caduceus var. *divergens* Harris
Isograptus caduceus var. *maximo-divergens* Harris
Isograptus manubriatus T. S. Hall
Isograptus pertensa (Harris)
Didymograptus sp.

In some areas, particularly at loc. 50, the fauna was extremely rich, but advanced metamorphism prevented specific determination. The Da2 beds contained:

Glyptograptus intersitus Harris and Thomas
Glyptograptus austrodentatus Harris and Keble
Trigonograptus wilkinsoni T. S. Hall
Cryptograptus tricornis Carruthers
Didymograptus cf. *d. v-deflexus* Harris

Didymograptus spp.
Tetragraptis sp.

Didymograptus cf. *v-deflexus,* recorded from loc. 25 may be a new species, but the material collected was insufficiently well preserved for a definite decision. At loc. 25, a richly fossiliferous bed, which could be traced for some 60 chains contained abundant *Didymograpti.* Unfortunately, the specimens were so thickly arrayed that specific identification was impossible.

The Da3 beds have a very restricted fauna:

Diplograptus decoratus Harris and Thomas
Glossograptus acanthus Elles and Wood
Didymograptus spp.

Da3 beds are quite thin and marked the top of the Ordovician sequence of Steiglitz. Exposures were restricted to synclinal hinges.

Description of Species

Isograptus pertensa, Harris

Isograptus caduceus var. *pertensa* W. J. Harris, *Proc. Roy. Soc. Vict.* 46 (1) Fig. 31, 1933.

Description: Rhabdosome large, scandent, consisting of two stipes 8 to 10 cm long, diverging at an angle of 340°. After initial divergence, the stipes are straight, with a width of 3 mm proximally, tapering to 1·5 mm distally. The thecae are spinose proximally, and number 7-8 in 10 mm. Distally, the thecae are slightly denticulate, sometimes lobate, with downward directed mucros, and number 6-7 in 10 mm. The sicular region is thick and spinose and the sicula is 6 mm long. A fine nema may be present.

Fig. 9
a. *Isograptus pertensa* (Harris) Detail of proximal region. Moorabool R. Sheoaks.
b. *Isograptus pertensa* (Harris) Sutherland's Ck. Steiglitz (Geol. Surv. Vict. 6719)

Remarks: Harris, who gave no formal description, regarded this form as a probable catagenetic ally of *I. caduceus* var. *divergens.* The wide variation in a number of diagnostic features of *Isograptus caduceus* were not fully studied by Harris, and there are, in *I. pertensa,* important morphological characters which lie outside the limits of variation in *I. caduceus.* The denticulate nature of the thecae is usually more pronounced than in *I. caduceus* while lobate thecae occurring distally are not found in *I. caduceus.* The angle of divergence of the stipes is significantly greater, and the width:length ratio of the stipes is considerably less; the sicular region is relatively thicker and more spinose.

Number of thecae in 10 mm varies from 8 proximally, to 6 distally; and the thecal openings are directed downward. In the proximal region the apertural margins of the thecae are straight; distally, they are concave.

In the 20 specimens collected from 3 localities there is little variation in the features described. Preservation of the whole rhabdosome is never good, and detail of the proximal and distal ends can rarely be studied in the same specimen.

Isograptus pertensa was collected from Ferguson's locality S_z 57 (loc. 13) on Sutherland's Ck, Steiglitz; from a southerly continuation of this bed (loc. 31) and from the south bank of the Moorabool R. at Sheoaks (loc. 68).

At the first of these localities the faunal assemblage is typically Da1. At loc. 68 the assemblage is transitional Ca3-Ya1. The range of *I. pertensa* is at least Ya1 to Da1.

Acknowledgements

We wish to record our appreciation of the following: The late Dr W. J. Harris for indicating some of the problems and for pointing out the interest of the mesoscopic structures; Adrian Beavis and students of Melbourne University in locating and collecting graptolites; the Geological Survey of Victoria for permitting us to examine Ferguson's graptolite collection, and type specimens of *Isograptus caduceus*; and to the University of Melbourne for a research grant which covered the cost of the field work, and also for payment of part of the cost of publication.

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Description of Plates

Plate 9

Fig. 1—Folds in sandstones, Moorabool R., Steiglitz-Meredith Road, Facing north. Note steep west dipping limbs. Length of section 15 ft. (A. P. Beavis photo)

Fig. 2—'Lozenge Structure' in sandstone. Grahame's Gully, Steiglitz. (A. P. Beavis photo)

Plate 10 (natural size)

Fig. 1—Photograph of cleavage plane (S1) showing lineation L1 deformed by S2. Lineation L2 is the fine fracture lines. Hanover Fault—Mariner's Gully.

Fig. 2—Conjugate L2 of siltstone with L1 trending diagonally across specimen. Ingliston.

Fig. 3—Crenulate lineation L2 in S1 of slate. L1 appears as fine deformed black lines. De Mott's Road, Anakie.

Fig. 4—Fine crenulate lineation L2 in cleavage plane S1 of cherty slate, Sutherlands Ck, Steiglitz.